

MICROSTRUCTURE AND CORROSION INVESTIGATION OF A356 VARYING REINFORCED WITH GRAPHITE AND GRANITE COMPOSITES

SATYANARAYANA TIRLANGI¹ & PUTTI SRINIVASA RAO²

¹Research Scholar, Department of Mechanical Engineering, Andhra University, Visakhapatnam, Andhra Pradesh, India

²Professor, Department of Mechanical Engineering, Andhra University, Visakhapatnam, Andhra Pradesh, India

ABSTRACT

Hybrid ceramic particulate reinforced Al-Si alloy matrix composites were prepared via stir casting process. Fine micron-sized Graphite and Granite powders were used. The corrosion behaviour of the composites was investigated using potentiodynamic polarization measurements. In the present investigation the corrosion measurements were carried out in 5% NaCl aqueous solution, 2.5% HCl. solution for predetermined time intervals and varying percentage concentrations of HCl solution at room temperature. Kinetics of corrosion effect on samples of Al-Si alloy, Al-Si/2wt% Graphite, Al-Si/2wt% Graphite & 2wt% Granite particles and Al-Si/2wt% Graphite & 4wt% Granite particles as reinforcement in composite are studied.

KEYWORDS: Corrosion, Al-Si Alloy, NaCl, HCl, Graphite & Granite

Received: Jun 28, 2019; **Accepted:** Jul 18, 2019; **Published:** Oct 15, 2019; **Paper Id.:** IJMPERDDEC201917

1. INTRODUCTION

Al-Si based alloys are used for the production of automotive engine and other vehicular transport components where light weight, high-modulus, and high-strength are required [1-5]. Although specialty high-strength aluminium alloys have been developed, “the addition of alloying elements and micro structural modification, can be costly, contain toxic elements, and often result in properties, which provide only a slight increase in mechanical properties. The demand for cost-effective lightweight, high-modulus, and high-strength materials has therefore led to the development of aluminium metal matrix composites (AMMCs)” [6-9]. Stir casting in the semi-solid state is the most common route for producing of AMMCs [10] in which low wettability of the reinforcing phase is challenging. One of the methods for improving reinforcement wetting is to reduce the surface energy of the solid-liquid interface by a metallic coating of reinforcements [11-13]. “In 1981, Rohatgi [14] suggested using a metallic layer (copper coating) on ceramic particles for increasing their wettability by molten aluminium. Later, Rajan et al. [15] reported in more detail the role of the coating on reinforcement particles on the wettability and interface characteristics of aluminium metal matrix composites”.

Corrosion resistance is an important material characteristic that should be taken into account in materials selection for industrial applications. In the case of AMMCs, “it has been reported that they have lower corrosion resistance compared to the base alloys due to the destruction of protective oxide film caused by the presence of ceramic particles” [16]. The metals tend to revert to their natural states through the processes of corrosion. Corrosion of metals and alloys used in industry in aqueous environment, including its environment, is an electrochemical reaction. In general, “corrosion products exist as a thin adherent film, which merely stains or tarnishes the metal and may act as a retardant to further corrosive action. In other cases, the products of corrosion are bulky and porous in character, offering

no protection” [17]. Keller and Edwards [18] reported that, “intermetallic particles dissolve faster than the aluminium rich matrix during the anodizing process and induce heterogeneous coatings with a low corrosion resistance”. Liu et al [19] stated that “the cathodic nature of the CuAl_2 particles, compared to the aluminium rich α -phase, rise the corrosion potential of the α -phase causing driving force for pitting corrosion in the α - solid solution. Electron beam welds of Al 2219 alloy exhibit superior corrosion properties compared to the base alloy due to dissolution of CuAl_2 particles and even distribution of copper in the matrix” [20]. Wang et al [21] stated that, “Cu in solid solution has more corrosion resistance than, when it is present as CuAl_2 , provided that the alloy is not aged to the point when it becomes susceptible to intergranular corrosion or stress corrosion. In addition, the Micro structural and the macro structural morphologies have a strong influence on the corrosion resistance” [22]. Recently pure metals macro structural [23] and binary alloy castings Microstructural [24] effect on corrosion resistance reported. “Corrosion resistance depends on the cooling rate imposed during solidification which affects the solute redistribution, dendrite arm size, and on the electrochemical behaviour of solute and solvent. The role of CuAl_2 intermetallic particles is important in conventional coatings or anodizing films [25]. There have been extensive investigation on the role of chloride ions in the breakdown of the passive film, re-passivation and initiation of localized corrosion of aluminium and high strength aluminium based alloys. The effect of alloying content [26], electrolytic composition [27], heat treatment [28] and mechanical stress on pitting and repassivation of aluminium based alloys in chloride media have been reported”. Aylor et al. [29] reported that the effect of reinforcement on pitting behaviour of aluminium base metal matrix composites and observed that “pitting corrosion attack on SiC/AA2024 alloy composites predominantly at the SiC/Al interfaces. Pits on the composites were greater in number, smaller in size, and shallower in depth than on the alloy. Feng et al. [33] investigated the pitting corrosion behaviour of SiCp/Al 2024 aluminium metal matrix composites. They reported intense corrosion of the composites by pit nucleation and propagation at the SiC/Al interface. Interfacial reactions between molten aluminium and SiC, generated intermetallic particles which formed micro-galvanic couples with the matrix. Zuhair et al., [33] investigated the electrochemical corrosion behaviour of powder metallurgy aluminium alloy 6061/ Al_2O_3 metal matrix composite in 3.5% NaCl aqueous solution. Two composite compositions 10 volume percentage and 30 volume percentage of sub-micron alumina particulates as the reinforcement phase by powder metallurgy processing were studied. Cyclic polarization tests carried to determine pitting potentials and re-passivation potentials in 3.5% NaCl solution. Several studies have indicated that the corrosion resistance of particle-reinforced composites depends on the composition of the base alloy, reinforcing particles, and corrosive environment” [34, 36].

In the present investigation the corrosion measurements were carried out in 5% NaCl aqueous solution, 2.5% HCl solution for predetermined time intervals and varying percentage concentrations of HCl solution at room temperature. Kinetics of corrosion effect on samples of Al-Si alloy, Al-Si-2wt% Graphite, Al-Si-2wt% Graphite & 2wt% Granite particles and Al-Si-2wt% Graphite & 4wt% Granite particles as reinforcement in composite are studied.

2. MATERIAL AND METHODS

In this study, “Al-Si alloy matrix with a density of 2.8 g/cm^3 was used as the matrix, while Graphite & Granite particles with a density of 2.1 g/cm^3 and 2.65 g/cm^3 an average particles size of $53\mu\text{m}$ were used as the reinforcement. The chemical analysis of Al-Si alloy matrix used in this investigation is 7.1%Si, 0.3%Mg, 0.01%Mn, 0.02%Cu, and 0.01% Ni. The MMCs with Al-Si alloy, Al-Si/2wt% Graphite, Al-Si/2wt% Graphite & 2wt% Granite particles and Al-Si/2wt% Graphite & 4wt% Granite particles were fabricated. The reinforced-particles with Al-Si MMCs have been produced by

using stir casting vortex method. The composites were shaped in the form of cylinder of height of 100 mm and 10 mm diameter. Al–Si alloy was charged into the crucible and heated to about 750 °C. Care was taken to ensure continuous and smooth flow of the particles addition in the vortex. The molten metal was stirred at 800 rpm under argon gas cover; stirring was continued for about 5 min after addition of Graphite & Granite particles to get the uniform distribution in the melt as shown in figure 2. During stirring small pieces of magnesium (0.5wt %) were added to the molten metal to enhance the wet tability of particles with melt. Homogenization treatment was carried out at 200 °C for 24 h to relieve the internal stresses and minimize the chemical in homogeneities, which may be present in the cast alloys”.

2.1 Processing of as Received Granite Powder

“The reinforcement material was granite particulates, which were procured from local stone crushing units. The chemical composition of the as received granite particles sample was given in table 1. A 500 grams weight of granite sample was taken in a graphite crucible and allowed to preheat in the muffle furnace at 850 °C for 4 hours to find out the loss on ignition. Preheated granite particulates after cooling to room temperature was washed with distilled water to remove the impurities and then dried at 120 °C for 48 hours to get rid of water as shown in figure 1.

The color of granite particulates will change to brackish from grey color. Dried granite has been sieved for 15 minutes using BSS meshes ranging in size from 100 to 350 by Sieve shaker. The results show that more than 70% by weight retained in -200 + 350 mesh with an average particle size of 53µm; hence this size was chosen as reinforcement for synthesis of hybrid composites”.

Table 1: Chemical Composition of Granite Particles

Constituent	Wt.%
Al ₂ O ₃	14.4
CaO	1.82
MgO	0.71
SiO ₂	72.4
K ₂ O	4.12
Na ₂ O	3.69
Fe ₂ O ₃	1.22



Figure 1: a) “Image of Granite Powder used for Synthesis of Hybrid Composites as Received Condition b) after Heat Treatment Condition”.



Figure 2: Stir Casting Setup and Casted Fingers in CI Die.

Figure 3 “(a) Shows the SEM micrograph of Al-Si alloy, a primary Si like needle structures are identified. (b) Graphite particle are identified and shown in magnified view”

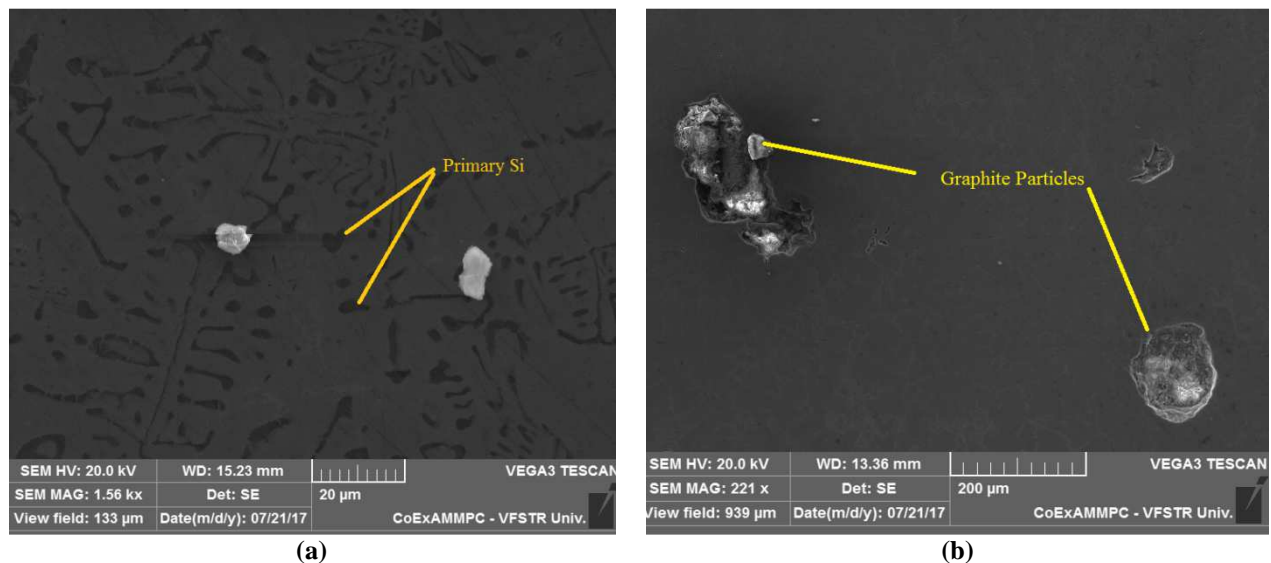


Figure 3: “(a) SEM Micrograph Al-Si Alloy (b) SEM Micrograph of Graphite Particles”.

Figure 4 “(a) Shows the SEM micrograph particle distribution in low resolution like needle structures is identified. (b) Graphite particle and Granite Dust are identified and shown in magnified view”

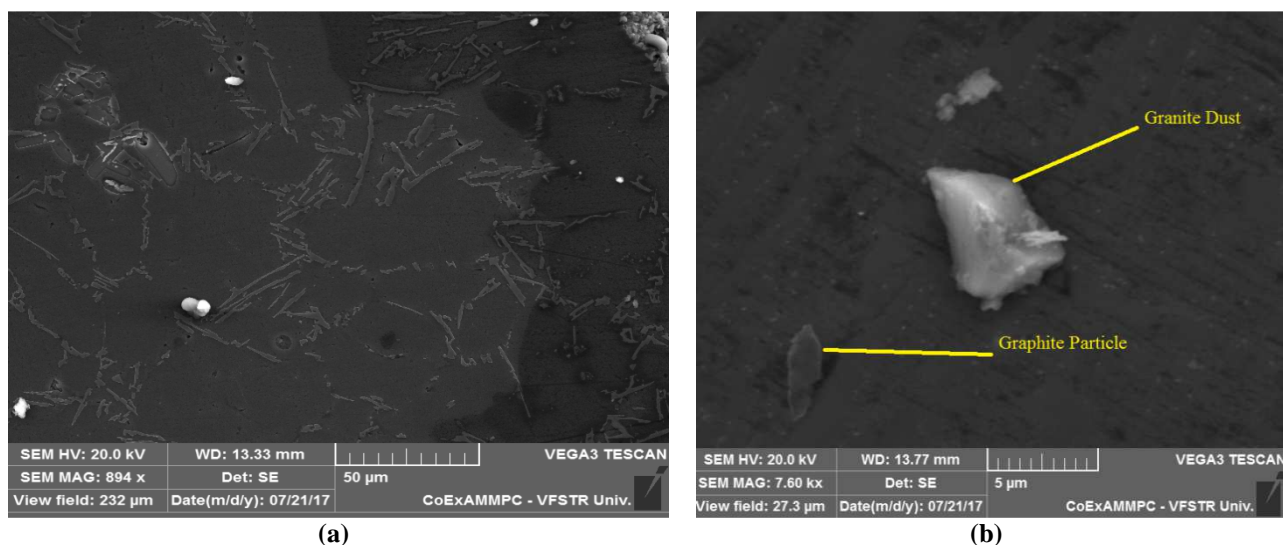


Figure 4: “(a) Particle Distribution in Low Resolution (b) SEM Micrograph of Graphite and Granite Particles”.

2.2 Density and Hardness Studies

“The average theoretical and measured density values of the Al-Si alloy and its respective composites were shown in figure 5. It was observed that the addition of 2% graphite + 4% granite particles into the Al-Si alloy matrix significantly decreases the density of the resultant composites in compare to the base alloy. The density of the composites decreases with increasing the percentages of graphite and granite particulates. The measured densities, however, were lower than that obtained from theoretical calculations”.

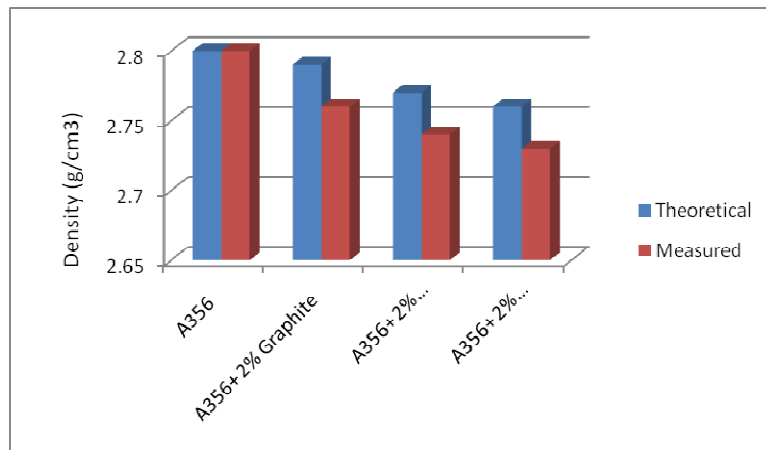


Figure 5: “Theoretical and Measured Densities of Al-Si Alloy and Composites”.

“The hardness of a material is a physical parameter indicating the ability of resisting local plastic deformation. The figure 6 shows that the hardness was increased from 84 VHN for Al-Si alloy to 110,124 and 135 VHN for composite 1, composite 2 and composite 3. This could be due to the presence of majority of the alumina and silica which are hard in nature as shown in figure 6”.

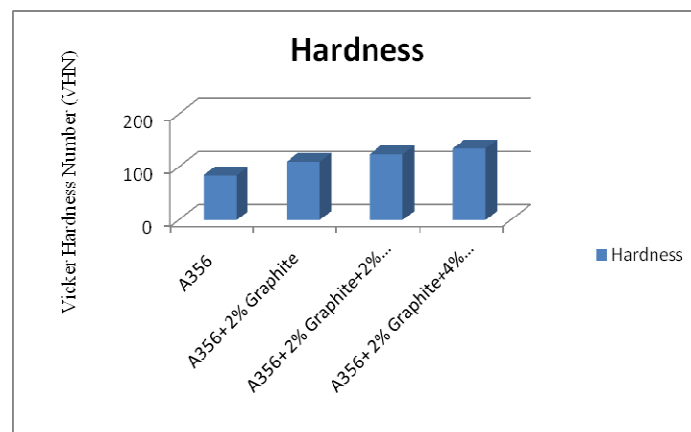


Figure 6: Hardness Values of Composite Samples.

3. MEASUREMENT OF CORROSION RATE

Corrosion rate can best be expressed in terms of “mpy” (mm per year). The following formula can be used to obtain mpy of any type of aluminium alloys and composite.

$$\text{Corrosion rate (mpy)} = 534 \text{ W/DAT}$$

“Where W represents weight loss in milligrams, D is density of the alloy and composite in gm/cm³, A is area of the specimen in cm² and T is immersion time in hours. The experimental setup was carried out using a system (Model: ACM Instruments GillAC–1130, UK) well linked to a PC and controlled by commercial software (model: GilAC). The experimental setup was shown in figure 7”.



Figure 7: Experimental Setup for Corrosion.

4. RESULTS AND DISCUSSIONS

“Two types of test solutions used, 5.0% NaCl aqueous solution and 2.5% HCl solution for pre-determined time intervals. Pitting corrosion occurs in aluminum, Al alloys and the composite, both in acidic and basic aqueous solutions between PH 4 and 8.5. Within this range aluminum is passive, because it is protected by its oxide film. The comparison curves are depicted in figure 7 and 8”.

4.1 Corrosion Effect in 5% NaCl Solution

“Figure 8 and 9 shows the effect of immersion time on corrosion rate on Al alloys and the composite in presence of 5% NaCl solution. Both alloys and composite show similar trend of dissolution i.e. Increase in dissolution with time. The following are the observations.

The nature of the potentio dynamic polarization curves reveals the alloy and composites was undergone natural passivation and the shape of potentio dynamic curves of alloy and composites under study show similar behavior. The slope of the linear sections of the anodic curves in relation to the x-axis above the E_{pit} point, together with a sudden increase in the current density, indicates rapid progress of corrosion pits.

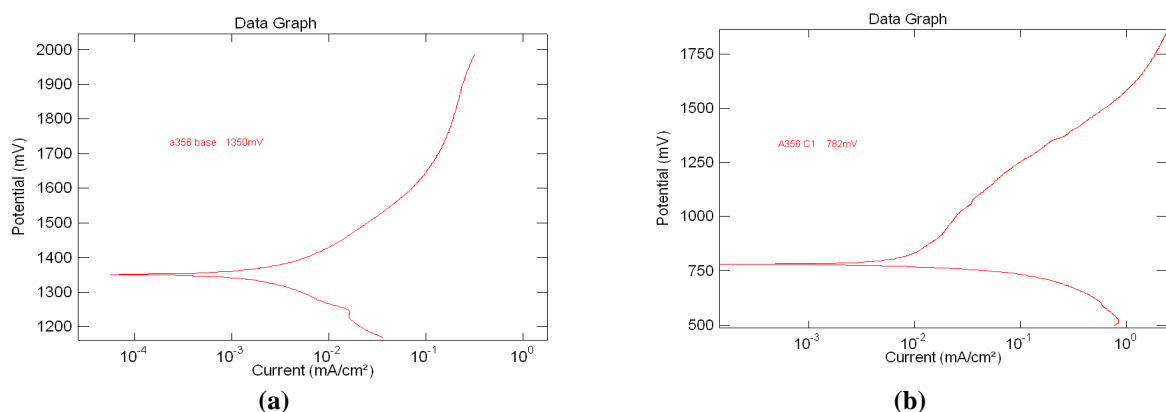


Figure 8: Potentio Dynamic Polarization Curves of the (a) A356 Alloy and (b) 2% Graphite.

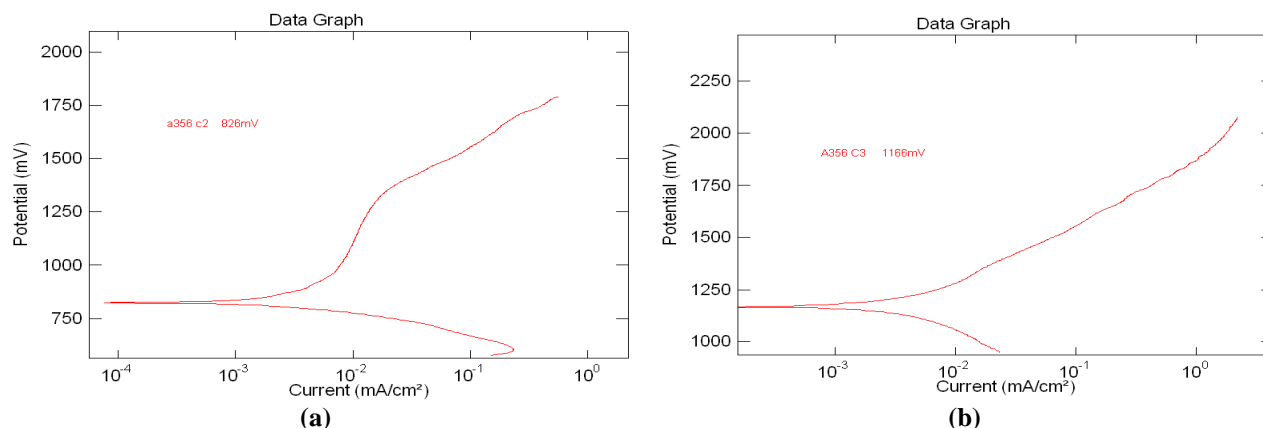


Figure 9: Potentio Dynamic Polarization Curves of the (a) A356+2% Graphite and 2% Granite (b) A356+2% Graphite and 4% Granite.

Figure 10. shows The values of E_{corr} for the A356 alloy and the A356 alloy + 2% Graphite + 4% Granite dust composite were 1350mV and 1166mV, respectively; and E_{pit} of the alloy and A356 alloy + 2% Graphite + 4% Granite dust composite were 1907mV and 1366mV, respectively; which indicates that the composite is similar potential to alloy. The ΔE values for alloy and composite were 647 and 200 mV, respectively. The slope of the linear sections of the anodic curves in relation to the x-axis above the E_{pit} point, together with a sudden increase in the current density, indicates rapid development of corrosion pits”.

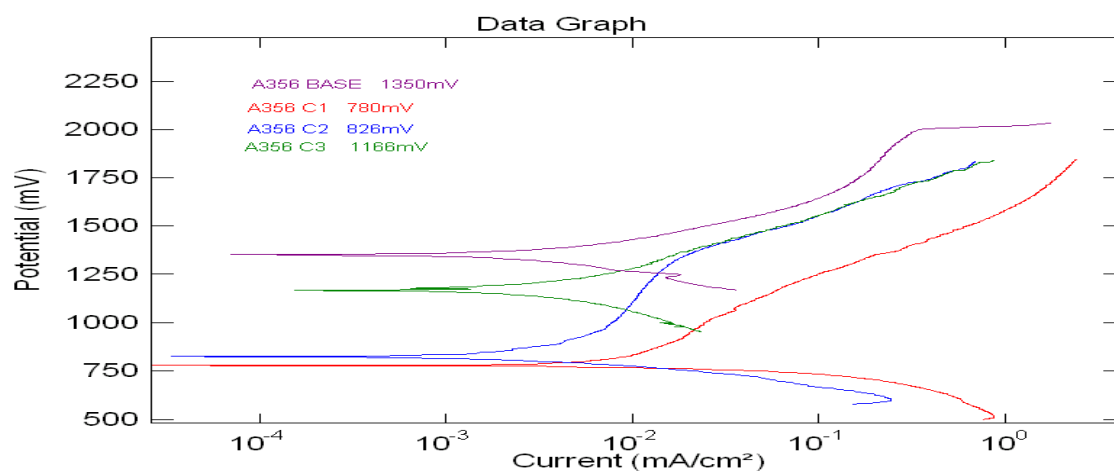


Figure 10: Potentio Dynamic Polarization Curves of the A356 Alloy and Composites.

Table 2: Electrochemical Data of A356 Alloy & A356 Alloy–Graphite (2)/Granite(2-4 w%) from the Corrosion Testing

Materials	$E_{corr}(mV)$	$I_{corr}(\mu A\ cm^{-2})$	$E_{pit}(mV)$	$\Delta E=E_{corr}-E_{pit}(mV)$
A356 Base	1350	0.06	1907	647
A356+2% graphite	780	0.89	1066	286
A356+2% graphite+2% granite	826	0.27	1341	515
A356+2% graphite+4% granite	1166	0.04	1366	200

Figure 11 Shows the corrosion effect on base alloy, pitting is observed at the grain boundaries. With increasing dissolution, exposure of newer surfaces triggered the corrosion rate.

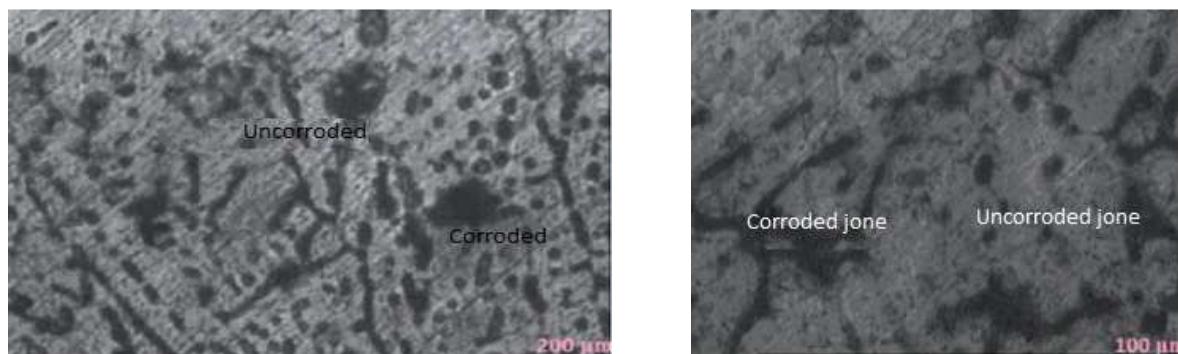


Figure 11: Optical Micrographs of Base A356 on Immersed in 5% NaCl Solution at 100µm and 200µm.

Figure 12. Shows the corrosion effect on 2% Graphite and 4% Granite Dust composite with lower contents of hybrid particles have shown initially lower rate of corrosion.

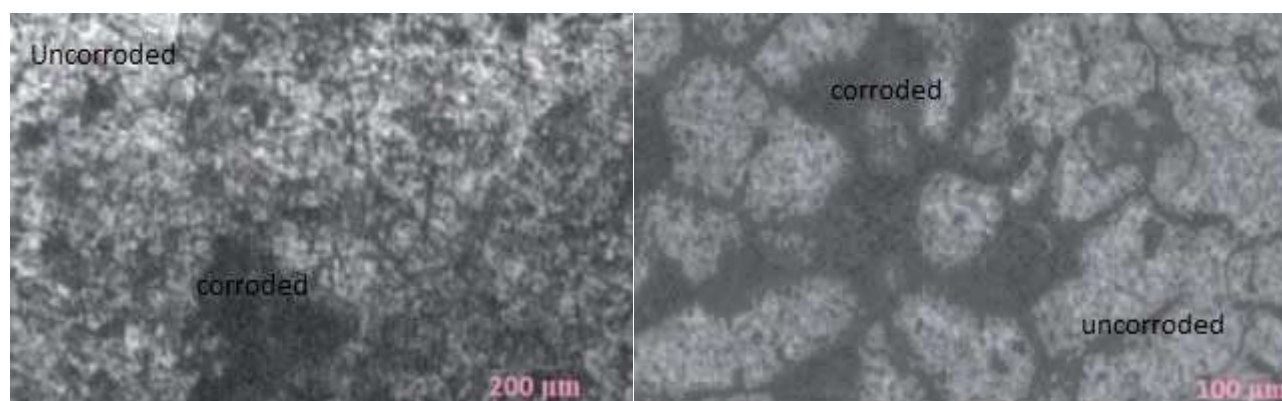


Figure 12: Optical Micrographs of Base A356 + 2% Graphite + 4% Granite Dust on Immersed in 5% NaCl Solution at 100µm and 200µm.

5. CONCLUSIONS

- Aluminium-Silicon(A356) alloy reinforced with ceramic particles of Granite and Graphite powder with 2wt% of Graphite and 2wt% & 4wt% of Granite were prepared by using vortex method.
- Corrosion studies of both alloy and composite carried by immersion in dilute solution of acidic and alkaline media and method of corrosion studies evaluated is by the loss in weight with time
- Both alloy and composite exhibits increased corrosion with increase in time of immersion in electrolyte.
- Composite A356+2% graphite+4% granite shows more resistance of corrosion compared to remaining composites and near to Base in 5% aqueous NaCl solution and 2.5% HCL solution.

REFERENCES

1. M K Surappa, *Aluminium Matrix Composites: Challenges and opportunities*, Vol. 28, Parts 1 & 2, February/April 2003, pp 319–334.
2. Miracle and Steven L. Donaldson, *Air force Research Laboratory*, pp 1–2.
3. S. Ray, *Review: Synthesis of cast metal matrix particulate composites*, J. Mat. Sci., 1993, Vol. 28, pp 5397–5413.
4. V Sethi, *Effect of Aging on Abrasive Wear Resistance of Silicon Carbide Particulate Reinforced Aluminium Matrix Composite*, M S Thesis, 2007, pp 77–78.

5. E Gikunoo, *Effect of Fly Ash Particles on the Mechanical Properties and Microstructure of Aluminium Casting Alloy A535*, M S Thesis, 2004. p. 97.
6. Kim CK, Park SY. 'A study on the fabrication and mechanical properties of SiC fiber Aluminium composites.' *J Korean Inst Met Mater* 1984; 22:125–92.
7. Seo YH, Kang CG (1999) *compo Sci Techno* 59:643.
8. Skolianos S (1996) *Mater Sci Eng A* 210:76.
9. Kang CG, Yoon JH Seo YH (1997) *J Mater Proc Techno* 166:30.
10. Terry, B.; Jones, G. *Metal Matrix Composites*; Elsevier Science: Oxford, England, 1990.
11. H. Noori, R.T. Mousavian, R.A. Khosroshahi, D. Brabazon, S. Damadi: *Surf. Eng.* 32 (2016) 391. DOI: 10.1179/1743294415Y.0000000035
12. N. Beigi Khosroshahi, R. Azari Khosroshahi, R. Taherzadeh Mousavian, D. Brabazon: *Surf. Eng.* 30 (2014) 747. DOI: 10.1179/1743294414Y.0000000035
13. N.B. Khosroshahi, R.T. Mousavian, R.A. Khosroshahi, D. Brabazon: *Mater. Des.* 83 (2015) 678. DOI: 10.1016/j.matdes.2015.06.027.
14. P. Rohatgi: *J. Mater. Sci.* 16 (1981) 1599. DOI: 10.1007/BF02396877.
15. T. Rajan, R. Pillai, B. Pai: *J. Mater. Sci.* 33 (1998) 3491. DOI: 10.1023/A:1004674822751.
16. A.S. Verma, N.M. Suri: *Mater. Today. Proc.* 2 (2015) 2840. DOI: 10.1016/j.matpr.2015.07.299.
17. Pourbaix M, 'Atlas of electrochemical equilibria in aqueous solutions', NACE Celecor, Huston, 1974.
18. Keller F, Edwards JD, 'Iron Age' 156 (1945) 75.
19. Liu Z, Chong PH, Skeldon P, Hilton PA, Spencer JT and Quayle B, 'Surf. Coat. Technol.' 200 (2006) 5514.
20. Rao SR, Reddy GM, Rao KS and Kamaraj Mand Rao KP, *Mater. Character.* 55 (2005) 345.
21. Wang L, Makhoulf M and Apelian D, *Int. Mater. Rev.* 40 (1995) 221.
22. Watkins KG, McMahon MA and Steen WM, *Mater. Sci. Engg. A* 231 (1997) 55.
23. Osorio WR, Freire CMA and Garcia A, *Mater. Sci. Eng. A* 402 (2005) 22.
24. Osorio WR, Freire CMA and Garcia A, *J. Alloys. Compo.* 1.397 (2005) 179.
25. Osorio WR, Spinelli JE, Cheung N and Garcia A, *Mater. Sci. Eng. A* 420 (2006) 179.
26. Elboujdaini M, Ghali E and Galibois A, *J. Appl. Electrochem.* 18(1988) 257.
27. Pyum SI and Lee EJ, *Electrochem Acta* 40 (1995) 1863.
28. Cabot PL, Garrido JA, Perez E, Moreira AH, Sumodjo PTA and Proud WG, *Electrochem Acta* 40(1995) p.447.
29. Aylor DM and Moran PJ, 'Effect of Reinforcement on the Pitting Behaviour of Aluminum- Base Metal Matrix Composites', *Journal of the Electrochemical Society*, 1985, Vol. 321, No.6, p. 1277–1281.
30. Abolusoro, O. P., & Akinlabi, E. T. *Wear and Corrosion Behaviour of Friction Stir Welded Aluminium Alloys-an Overview*.
31. Feng Z, Lin C, and Luo J, 'Pitting Behaviour of SiCp/2024 Al Metal Matrix Composites, *Journal of Materials Science*, 1998, Vol. 33, p. 5637–5642.

32. Kumar, J. M. *Fabrication and Testing of Aluminum Based Composite Material*.
33. Zuhair M. Gasem and Amro M. Al-Qutub, "Corrosion Behaviour of Powder Metallurgy Aluminium Alloy 6061/AL₂O₃ Metal Matrix Composites", 6th Saudi engineering conference, 2002. vol 5 P. 271–280.
34. Nunes PCR and LV Ramanathan, 'Corrosion Behaviour of Alumina- Aluminum and Silicon Carbide-Aluminum Metal Matrix Composites', *Corrosion Science*, Vol. 51, No. 8, 1995, p. 610–617.
35. Reddy, T. T. *Corrosion and Wear Behavior of Aluminum Alloy Hybrid Metal Matrix-a Review*.
36. Trzaskoma PP, 'Pit Morphology of Aluminium Alloy and Silicon Carbide / Aluminum Alloy Metal Matrix Composites' *Corrosion Science*, Vol. 46, No. 5, 1990, p 402–409.
37. Radhi, N. S., & Al-Khafaji, Z. A. I. N. A. B. *Investigation Biomedical Corrosion of Implant Alloys in Physiological Environment*.

AUTHOR'S PROFILE



Mr. SATYANARAYANA TIRLANGI is born in Visakhapatnam, Andhra Pradesh, India. He received B.Tech from JNTU (K) Kakinada, Andhra Pradesh, India. He received his ME from Andhra University, Andhra Pradesh, India. He is currently pursuing PhD Part Time in Andhra University, Andhra Pradesh, India. He has 8 years of teaching experience in engineering colleges. He published SCI and International Journals in various Publications. His research interest in Composite Materials, Surface coatings, Powder Metallurgy and Welding Technology.



Dr PUTTI SRINIVASA RAO is born in Vijayawada, Andhra Pradesh, India. He received B.Tech in the year 1995 from Bangalore University, Karnataka, India. He received his MTech in the year 2000 from JNTU (H), Hyderabad, Telangana, India. He received PhD in the year 2012 from Andhra University, Andhra Pradesh, India. He has 13 years of teaching experience in Mechanical Engineering Department, Andhra University, Andhra Pradesh, India. He published SCI and International Journals in various Publications. His research interest in Composite Materials, Vibrations and Welding Technology